SIMULTANEOUS PHASE MEASUREMENT INTERFEROMETRY FOR LASER INTERACTION IN AIR

ASIAH BINTI YAHAYA

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To my mother

CHE SUM SANAPI

My husband

MANAN MUNHAMAD JAIB

My children

KAMILAH, KAMIL MOHSEIN, NUR ATIKAH,

HAFIZ ARIF and KHAIRUL AIMAN

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ABSTRACT

The problem encountered when evaluating phase profile of laser interacted images with direct phase mapping method, using only one interferogram, was in the form of phase ambiguity. This was due the existence of extra fringes in the interacted region of the interferogram. The very sensitive Phase Measurement Interferometry (PMI) also suffers from environmental factors such as vibrations and air turbulence. The new system developed to reduce phase ambiguity was a three outputs interferometer, which was designed to capture three interferograms simultaneously. The fast photography incorporated in the system managed to eliminate the problems of vibrations and air turbulence. The three interferogarms were initially arranged to have a phase difference of 90° with one another; a requirement for quadrature imaging. Since the interferograms were captured simultaneously, they would carry different phase information of the event. The acoustic wave generated by laser interaction caused the fringes to deviate accordingly to the change in its phase. From their three intensities, appropriate phase shifting algorithms were selected to produce a single final phase change profile of the interaction event. The result obtained revealed a significant contribution to the reduction in phase ambiguity. The changes in phase were associated with the changes in refractive index, density and pressure. The values of pressure change were compared to those obtained from the conventional fringe analysis. Measurements made at time delay of 3.6 μs indicated a 26 % difference. As the delay increased, this difference seemed to decrease and at around 5.0 μs both techniques seemed to produce agreeable results. The nonlinear profiles of the maximum pressure change with time using the two techniques were presented. Despite the high complexity of the experimental setup, the system managed to fulfill the objectives for its development.

ABSTRAK

Pengukuran fasa bagi interaksi laser dengan kaedah pemetaan fasa secara terus dengan satu interferogram sering dibelenggu masaalah kesamaran disebabkan oleh penambahan pinggir yang berlaku. Pengukuran fasa secara interferometri yang sangat sensitif ini juga dibebani masaalah yang berkaitan faktor sekitaran seperti getaran dan gelora udara. Sistem yang dibina bagi mengurangkan masaalah kesamaran fasa adalah interferometer dengan tiga output bagi merakam tiga imej serentak. Sistem fotografi berkelajuan tinggi yang digunakan untuk merakam imej serentak dapat mengatasi masaalah gelora udara dan getaran. Ketiga-tiga interferogram diatur supaya berbeza fasa 90° antara satu sama lain, iaitu keperluan untuk pengimejan kuadratur. Oleh kerana ketiga-tiga interferogram dirakam serentak, maklumat fasa yang dibawa adalah berbeza bagi sesuatu peristiwa. Algoritma anjakan fasa yang dipadankan dengan sistem yang dibina dapat menghasilkan satu profil perubahan fasa bagi interaksi laser. Hasil yang diperolehi menunjukkan satu penemuan yang signifikan untuk mengurangkan masaalah kesamaran fasa bagi interferogram interaksi laser. Profil perubahan indeks biasan, ketumpatan dan juga tekanan yang sepadan juga dapat dibentuk. Perubahan ini dibandingkan dengan perubahan yang diperolehi melalui kaedah yang terdahulu iaitu penganalisaan pinggir. Kiraan ketika masa tundaan 3.6 μs, mencatakan perbezaan 26 %. Namun apabila masa tundaan ditambah peratus perbezaan berkurang. Disekitar 5.0 μs, kedua teknik yang digunakan mencapai kesamaan. Walaupun menghadapi pelbagai cabaran di setiap peringkat penyelengaraan, hasilnya membuktikan bahawa semua objektif yang di kemukakan bagi pembangunan projek ini dapat dipenuhi.

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LIST OF ABREVIATIONS

ξ	-	spatial frequency coordinate
η	-	high frequency noise
2D, 3D	-	two and three dimensional
α	-	phase step
atm	-	atmospheric pressure
B	-	Bulk modulus
c	-	Velocity of light
CCD	-	Charge Couple Device
CCIR	-	Comite Consultive International Radio
c_R	-	Rayleigh wave velocity
ΔF	-	fringe shift
Δf	-	fractional fringe shift
$\Delta\phi$	-	phase change
ΔL	-	optical path difference
Δn	-	change in refractive index
ΔP	-	change in pressure
$\Delta\rho$	-	change in density
E	-	electric field amplitude
f	-	frequency

FFT	-	Fast Fourier Transform
γ	-	coherence modulation
HD	-	Horizontal drive synchronization
He-Ne	-	Helium Neon
I	-	intensity
ISA	-	Industry Standard Architecture
λ	-	wavelength
LASER	-	Light Amplification by Stimulated Emission of Radiation
MHz	-	MegaHertz
μm	-	micrometer
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
μs, ns	-	microsecond, nanosecond
MW	-	MegaWatt
n	-	refractive index
Nd:YAG	-	Neodymium: Yttrium Aluminium Garnet
PAL	-	Phase Alternation Line
PMMA	-	polymethyl methacrylate
PMI	-	Phase Measurement Interferometry
PSI	-	Phase Shifting Interferometry
ρ	-	density of medium
TTL	-	Transistor Transistor Logic
VD	-	Vertical drive synchronization
w	-	width distribution of laser beam

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Optical measurements are playing a much more important role today than they ever did in the past. The demands on measurement accuracy have increased, driven by the high-stake scientific and technological applications. One such example of the immeasureable importance of measurements and their critical nature is that of the Hubble Space Telescope. The imperfections in the primary mirror arose from the defective measurements of the mirror's surface contours were discovered after the telescope was launched. However, the imperfections causing blurred vision were finally spectacularly corrected in orbit (Rastogi, 1997). .

Laser interferometry provides the non-contact, non-destructive precision measurements necessary for industrial purposes. The interaction of laser radiation with matter and their applications have been studied extensively ranging from the higher power laser applications in laser fusion, laser processing, laser chemistry, laser annealing, non-linear optics, medicines, laser monitoring of the atmosphere to the low power laser applications in optical fiber communication and spectroscopy.

As measurement precision increases, laser interferometry is gaining acceptance in applications as exotic as gravitational-wave detection as a mundane; but equally important as inspection of automotive engine components (Lerner, 1999). Other applications of interferometry include Fourier-transform infrared spectroscopy; imaging of 3-D surface profiles; laser wavelength determination; and the manufacture of optics gigabit hard-disk drives, fuel-delivery systems in diesel engines, Pentium computer processors and contact lenses (Peach, 1997).

In studying the acoustic waves due to laser interaction, the measurements of the phase change can be made based on the fringe shift of the interferograms and also on the change in the intensity level or the gray scale of the fringes. The propagation of the waves will change the density and therefore the refractive index of the medium. This changes the optical path lengths, which result in the shifting of the fringes in the interference pattern. Using Abel inversion technique, the change in refractive index of the medium can be related to the change in pressure of the resulting wave.

In this work, an interferometry system for phase measurement will be developed to study the changes in pressure of the acoustic waves produced by laser interaction. The system is designed to overcome the problem of phase ambiguity due to extra fringes associated with laser interactions. As phase measurement interferometry is a very sensitive and very precise measurement, its environmental effects should also be taken care of. Thus, the system designed will also include eliminating the problems of air turbulences and also vibrations. Error contaminations are unavoidable in the production of the images. But, these errors would not be such a nuisance if they are of the same nature and come from the same sources. This would simplify the noise filtering process. Phase calculations will surely benefit from this type of images.

1.2 Objectives of the study

There are some common drawbacks and limitations to the use of interferometry for phase measurements. The spherical nature of the acoustic waves produced by laser interaction but viewed from a slight tilt, can sometimes produce extra fringes in the interferogram. In analysis, this will lead to phase ambiguities. Environmental factors, such as vibrations and air turbulence, have tremendous effects on phase calculations due to the very sensitive nature of the interferometry system. Various time dependent noises are not excluded in this type of phase measurement. Previously, phase measurement using inteferometric methods can be long and tedious processes, involving large amount of data. However, modern computer software and programming can overcome the problem.

The objectives of this research are:

1 To develop a direct phase measurement system that will be able to measure phase profile of laser interactions.
2 To overcome the problem of phase ambiguity due the effects of extra fringes in the area of acoustic wave disturbance.
3 To improve the system by eliminating the factors of air turbulence and vibrations.
4 To evaluate the pressure profiles of the waves produced.

1.3 Scope of Study

The scope of study includes the development of the system that consists of a three outputs interferometer, a fast photography unit, a synchronize-and-trigger unit and also the image-processing unit. The interferometer was a Mach Zehnder interferometer, which was modified to suit the simultaneous-image capture requirement. The fast photography unit made use of the 1 ηs illumination from the pulsed Nitro-dye laser. The trigger and synchronize unit is an electronic system that connect, control and synchronize the whole operation. The image-processing unit includes the writing of computer programs to obtain the phase change for this system. The phase change will be determined by the intensity distribution of the interferograms.

The phase of the three simultaneously captured interferograms differed by 90° from one another. This will allow the wave to be assessed using three different phase information; with the intention of minimizing the ambiguity problem. The algebraic combination of their intensities will provide the associated phase change due to laser interaction. The algorithms for phase measurement in this work are based on phase-shifting algorithms.

There are two methods of phase analysis namely fringe analysis and phase mapping. This work will emphasize the phase mapping method, based on three interferograms that are captured simultaneously. However, comparisons will be made with the conventional fringe analysis.

The assumption made in this study is the spherically symmetrical nature of the acoustic waves produced by laser interaction. With this assumption and the Abel inversion technique, the phase change can be converted to the change in the refractive index and density and finally to the change in pressure of the associated sample.

Visual phase representations such as 3-D images will be produced to enable thorough observations of the changes taking place at any location of the interferogam to be made. A computer program will be developed for this purpose.

1.4 Thesis layout

Chapter 2 describes the literature survey of the work done by the previous researchers in the same discipline. It reveals the correlations between fringe deviation and phase change, which are then related to changes in the refractive index, density and pressure of acoustic wave produced by laser interaction. Various methods and algorithms were designed and implemented by previous researchers, to suit the various need in interferometry. There were tremendous efforts put in to overcome the errors that accompany the system. However, no one particular method or algorithm can eliminate most of the errors associated with interferometry measurements. Usually, a system or a technique is developed to overcome certain problems only.

The system designed and built for this work is described in Chapter 3. The interferometer system, with its three outputs designed to be at 90° out of phase from one another, was a modified Mach Zehnder interferometer. A fast photography unit attached to the system was used to capture the images of fast events (1 ns) such as laser interaction. This was also used to eliminate environmental factors such as vibrations and air turbulence. The trigger and synchronize electronic system acted as the control for the start of the event and the delay between laser interaction and its image capture.

Chapter 4 described the preliminary work done with the system and the preparations of the system before it is ready to take measurements for phase analysis. Firstly, the system was arranged so that the intensity of the three images was about the same. Secondly, the three outputs of the interferometer must be at a phase difference of 90° between the images. This was obtained by rotating the analyzers in front of the detectors, until the right combinations that produced the required phase different was found. Then, there was also the magnification factor of the image that must be recorded in order to obtain the correct dimensions of the event.

Single interferometry phase analysis was described in Chapter 5. The methods used here were the fringe analysis and the phase mapping using Fourier transform analysis. These methods were known to be capable of producing reliable results. In this work, fringe analysis was capable of producing the required phase profile but the work involved was eye-straining, long and tedious. However, with phase mapping method on laser interacted interferograms, even though easier, sometimes, could result in phase ambiguity. This phase ambiguity is shown in this chapter.

The phase measurement method involving three simultaneously captured images was revealed in Chapter 6 of this work. It showed how the change in phase of laser interacted interferogram can be calculated using two different phase-shifting algorithms. The evaluation of the associated change in density, refractive index and also pressure profiles of laser interaction in air were made. Pressure profiles from both; the simultaneous and the fringe measurement techniques were produced for comparison. Visual representations in the form of 3-D images of the events were produced to enhance the quantitative results. The author also quoted the advantages of the simultaneous image analysis over the single interferometry analysis in overcoming the current ambiguity problem of images produce by laser interaction. Some error factors that could affect these measurements with the present system were also mentioned.

Besides the physical limitations and challenges faced with the present system, it was concluded that the objectives of this project were fulfilled. This was concluded in

Chapter 7. However, the work must go on and the author stated a few ideas as to improve the accuracy of the present system. Recommendations on the expansion and the diversification of the present scope were also mentioned.

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